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Ka-band Phase Measurement System for SWOT mission

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Abstract

The KaRIn (Ka-band radar interferometer) instrument for SWOT (surface water ocean topography) mission faces unique challenges in terms of phase stability and group delay stability requirements to achieve centimeter level accuracy for height measurements. Conventional altimetry assumes nadir point return and measures a single range. SWOT will require additional angle of arrival information to provide swath coverage. Errors in differential phase and common group delay can both act as primary sources of systematic errors in determining the height using interferometric data.

The ground support equipment (GSE) necessary for the performance requirements verification gets a fraction of the error allocation from the instrument. A phase measurement system capable of measuring millidegrees and working with pulsed excitation is developed and the preliminary results are described in this paper.

1. Introduction

SWOT is an earth-sensing mission specifically designed for height measurement of oceans and terrestrial water bodies [1]. It will address key questions like spatial and temporal variability of the world's surface freshwater storage and discharge, flood prediction and water resource management. The principal instrument for SWOT is KaRIn. The interferometer derives height information based on the relative delay between the signals measured by two antennas separated by a fixed distance [2] [3]. In case of KaRIn, this distance or baseline is 10m. Group delay and differential phase errors in the instrument cause systematic errors leading to errors in the estimate of height.

A 15km long temperature controlled FODL (fiber optic delay line) is used to characterize the radar interferometric performance. To make sure that the GSE (FODL in this case) does not dominate the phase and time-delay stability, FODL gets 1% of the overall radar error allocation. This leads to a 8ps common group delay requirement on a 15km optical fiber. For thermal vacuum measurements long waveguide runs (~3m) will be used to connect GSE to KaRIn. The differential phase stability requirement for KaRIn places constraints on the waveguide runs.

Individual components used in the radar can be characterized for phase stability using COTS (commercial off-the-shelf) equipment such as NXA-50 [4]. However, NXA-50 offers only a CW source. In order to make flight like measurements, capability to generate different pulse width chirps repeated at fixed PRF (pulse repetition frequency) is necessary. A custom GSE built to characterize some radar components like the EIK (extended interaction klystron) [5] and other GSE used for performance measurements is described here. The phase measurement system described in this paper is referred to as PHEMUS in rest of the paper. The next sections describe the measurement principle, measurement setup and preliminary results.

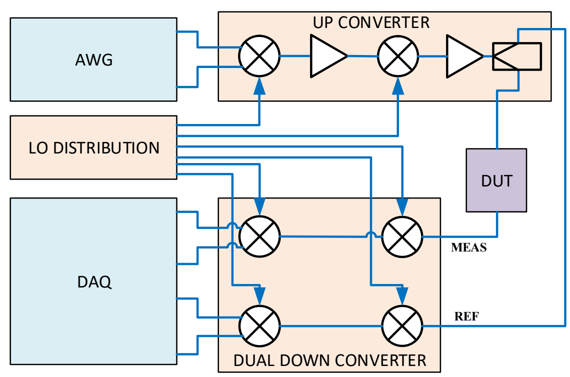

Figure 1: Simplified block diagram of PHEMUS

2. Measurement Principle

Figure 1 shows a simplified block diagram of Phemus. The digital portion of PHEMUS generates an I (in-phase), Q (quadrature) pair using an AWG (arbitrary waveform generator). This I, Q pair is up converted to Ka-band using a dual mixing approach with two LOs: one at 13.75 GHz and other at 22GHz. The Ka-band pulse train is divided in two signal paths: 1) reference path and 2) measurement path.

The DUTs (waveguides/EIK/FODL) are inserted in the measurement path and the output is amplified to correct level before down conversion into the MEAS I, Q output pair at baseband. The reference path goes through an identical receiver chain and produces a REF I, Q output pair. The two receiver chains run next to each other undergoing similar temperature fluctuations and vibrations. When the two received signals are cross-correlated all the common mode signal is removed and the group delay of DUT is obtained using equation (1).

$$\text{GD}=\frac{d}{d\omega}(\arg(FFT(MEAS)*FFT(\overline{REF})^{*})) \quad (1)$$

For dual-channel DUTs, like parallel waveguides, information is sought on differential phase. In such cases, both MEAS and REF channels are used respectively for the two channels of the DUT.

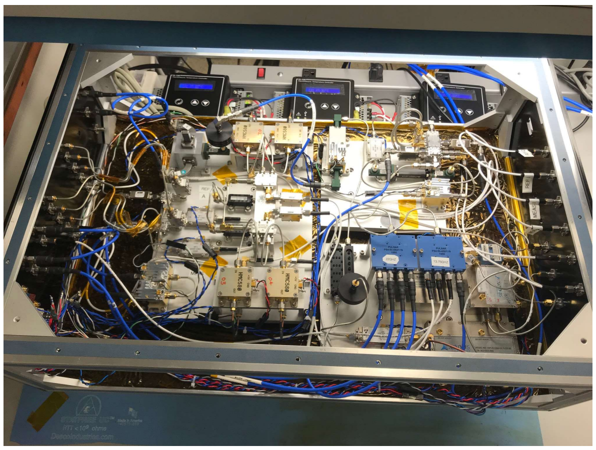

Figure 2: Photograph of RF portion of Phemus

4. Measurement Setup

An NI AWG is used to create baseband chirps. A 10MHz TCXO located in the RF chassis provides the master 10 MHz reference for all the RF and digital hardware. The I and Q chirp waveform files are generated using Matlab and then loaded into the AWG. The pulse width is 10us with a one-sided bandwidth of 105 MHz and the pulse repetition frequency (PRF) is 8 KHz. The AWG output is filtered before it is up-converted using an IQ mixer to Ku band. The Ku signal is amplified and up-converted a second time producing a Ka-band chirp centered around 35.75 GHz. The amplified signal is filtered and fed to a driver amplifier, which then drives a power amplifier to generate the desired output signal.

Two Identical downconverter chains are mounted next to each other on a temperature controlled plate so that any residual temperature fluctuations and or mechanical vibrations will be common to both chains. There is a 2.4^{0}C peak-to-peak change in ambient temperature caused by the laboratories HVAC system. The plate is maintained at 25^{0}C using thermoelectric coolers to minimize the temperature fluctuations caused by these ambient temperature changes. Thick plates are used to mount the RF hardware as they present a higher thermal inertia. All plates are enclosed in a box as shown in figure 2 and the box walls are covered with insulating foam to reduce thermal variations.

The downconverter chains are made modular by adding the ability to add Ka-band and Ku band amplifiers, depending on the DUT being tested and the corresponding signal level in the MEAS channel. The outputs of both the MEAS and REF channel downconverters are each in an I/Q format. Each I/Q pair is fed to an NI data acquisition card that samples at 400 M samples/sec. Special care is taken in the dual down converter to use phase matched cables and filters with similar group delays.

The two LO signals are generated internal to the RF portion of PHEMUS and are mounted on a third temperature controlled plate. The 13.75 GHz and 22 GHz LO sources are locked to a stable oscillator mounted on the same temperature controlled plate. Each of the two LO outputs are amplified and divided using four-way splitters such that each LO is routed to its three corresponding mixers (two in the downconverter, and one in the up-converter). The fourth splitter port for each LO is connected to a test port on the front panel. The LO sources are selected to have low phase noise.

Data acquisition is able to sample at 400M samples/sec rate, producing large amounts of data. Each minute of recorded data corresponds to about 15GB of hard disk space. RAIDs are used for high speed data collection. The processed data is transported to a different machine for further processing.

5. Results

The first step towards verification is a loopback measurement where no DUT is inserted. Both channels of the up-converter are connected to the dual down converters essentially creating identical REF and MEAS paths. This configuration should theoretically cancel all the common mode phase variations due to temperature and vibrations and esablishes the measurement noise floor.

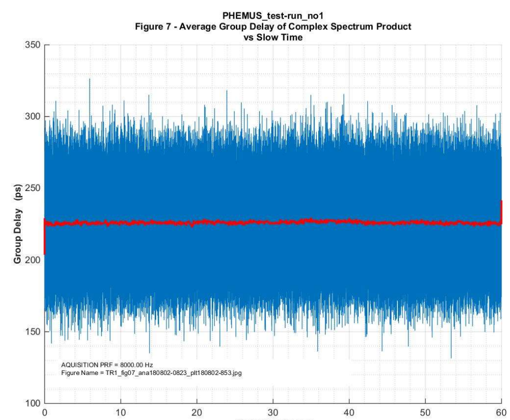

Figure 3: Average group delay vs slow time

Figures 3 and 4 show the average group delay and average phase versus slow time, respectively, for a two minute data take. Each point in the slow-time plot represents the average phase (or group delay) of a pair of chirps. The power spectral density (PSD) is then taken as an FFT of the slow-time series. Figures 5 and 6 show the PSD of differential phase and group delay, respectively. The yellow lines show the requirement set by the project.

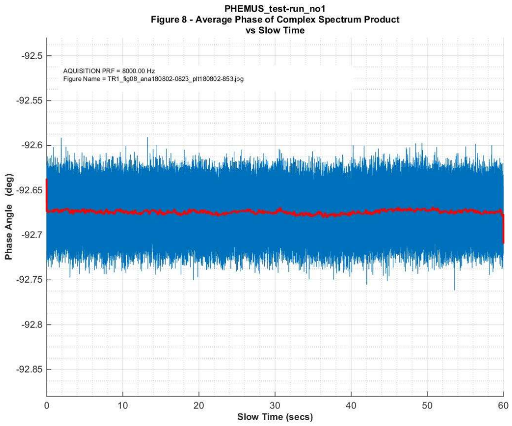

Figure 4: Average phase vs slow time

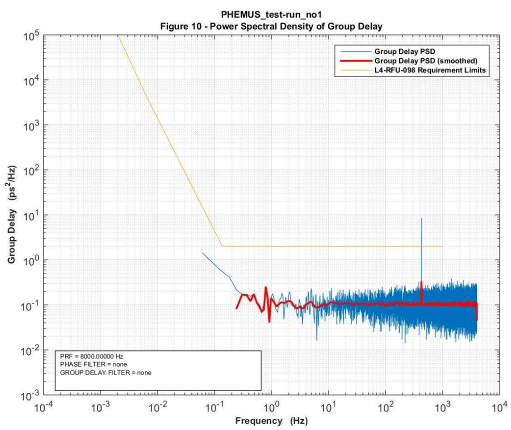

Figure 5: PSD of group delay

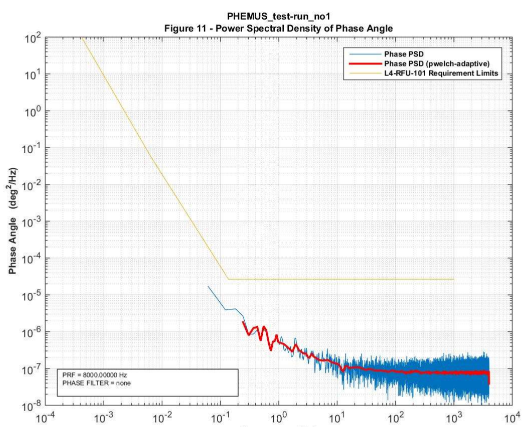

Figure 6: PSD of differential phase

6 Summay

A phase measurement system capable of measuring millidegrees and working with pulsed excitation is developed for the Ka-band radar interferometer for the SWOT mission and the preliminary results are described in this paper.

7 Acknowledgements

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